21cm Limits on Decaying Dark Matter and Primordial Black Holes

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Collaboration with: B. Dutta, Y. Gao, Y. Ma, and L. Strigari; arXiv:1803.09390

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Motivation behind 21cm line

Corresponds to the neutral Hydrogen spin transition

Transition wavelength of 21 cm

Provides an additional period for constraint

Occurs during the dark age of the Universe

Approach

Energy Injection into the Universe (Model Dependent)

Energy Absorption through Various Channels

-Effective Efficiency (Model Dependent)

Energy Effects Evolution of the Intergalactic Medium Altered

Evolution Leaves a Measurable Imprint

Energy Injection

Decay - density dependent

$$\left(\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\right)_{\mathrm{dec}} = \frac{1}{\tau_\chi}\rho_{\mathrm{c}}c^2\Omega_{\chi,0}(1+z)^3$$

Annihilation - density^2 dependent*

$$\left(\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\right)_{\mathrm{ann}} = \rho_{\mathrm{c}}^2c^2\Omega_{\chi,0}^2\frac{\langle\sigma v\rangle_\chi}{M_\chi}(1+z)^6$$

Primordial Black Holes (PBH) - density dependent†

$$\left(\frac{\mathrm{d}E}{\mathrm{d}V\mathrm{d}t}\right)_{\mathrm{BH}} = \frac{\dot{M}_{\mathrm{BH}}}{M_{\mathrm{BH}}}\rho_{\mathrm{c}}c^2\Omega_{\mathrm{BH},0}(1+z)^3$$

$$\dot{M}_{\mathrm{BH}} = -5.34\times10^{25}F(M_{\mathrm{BH}})M_{\mathrm{BH}}^{-2}\,\mathrm{g}^3\,\mathrm{s}^{-1}$$

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*Madhavacheril, Sehgal,and Slatyer; arXiv:1604.02457

†Carr, Kohri, Sendouda, and Yokoyama; arXiv:0912.5297

Absorption Channels*

Hydrogen Ionization

$$I_{\mathrm{i}}(z) = f_{\mathrm{i}}(E, z)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)E_{\mathrm{i}}}$$

Lyman-Alpha Excitation

$$I_{\alpha}(z) = f_{\alpha}(E, z)(1 - C)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)E_{\alpha}}$$

Gas Heating

$$K_{\mathrm{h}}(z) = f_{\mathrm{h}}(E, z)\frac{\mathrm{d}E/\mathrm{d}V\mathrm{d}t}{n_{\mathrm{H}}(z)}$$

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*Liu, Slatyer, and Zavala; arXiv:1604.02457

Belotsky and Kirillov; arXiv:1409.8601

Slatyer; arXiv:1211.0283

Gas Evolution*

Ionization Fraction

$$\frac{\mathrm{d}x_e}{\mathrm{d}z} = \left(\frac{\mathrm{d}x_e}{\mathrm{d}z}\right)_{\mathrm{orig}} - \quad \frac{1}{(1+z)H(z)}\left(I_{\mathrm{i}}(z) + I_{\alpha}(z)\right)$$

Medium Temperature

$$\frac{\mathrm{d}T_{\mathrm{IGM}}}{\mathrm{d}z} = \left(\frac{\mathrm{d}T_{\mathrm{IGM}}}{\mathrm{d}z}\right)_{\mathrm{orig}} - \quad \frac{2}{3k_{\mathrm{B}}(1+z)H(z)}\frac{K_{\mathrm{h}}(z)}{1+f_{\mathrm{He}}+x_e}$$

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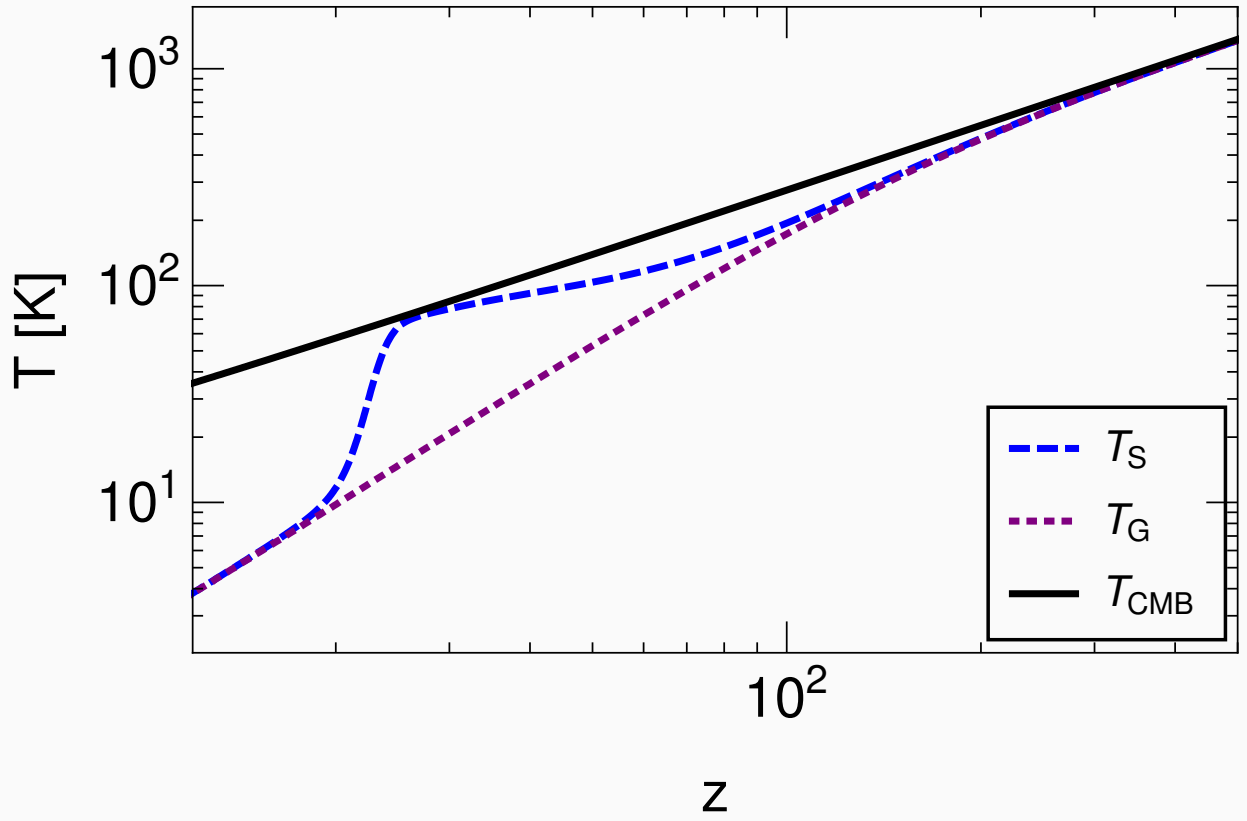
*Liu, Slatyer, and Zavala; arXiv:1604.02457

Belotsky and Kirillov; arXiv:1409.8601

Slatyer; arXiv:1211.0283

Wouthuysen-Field Effect*

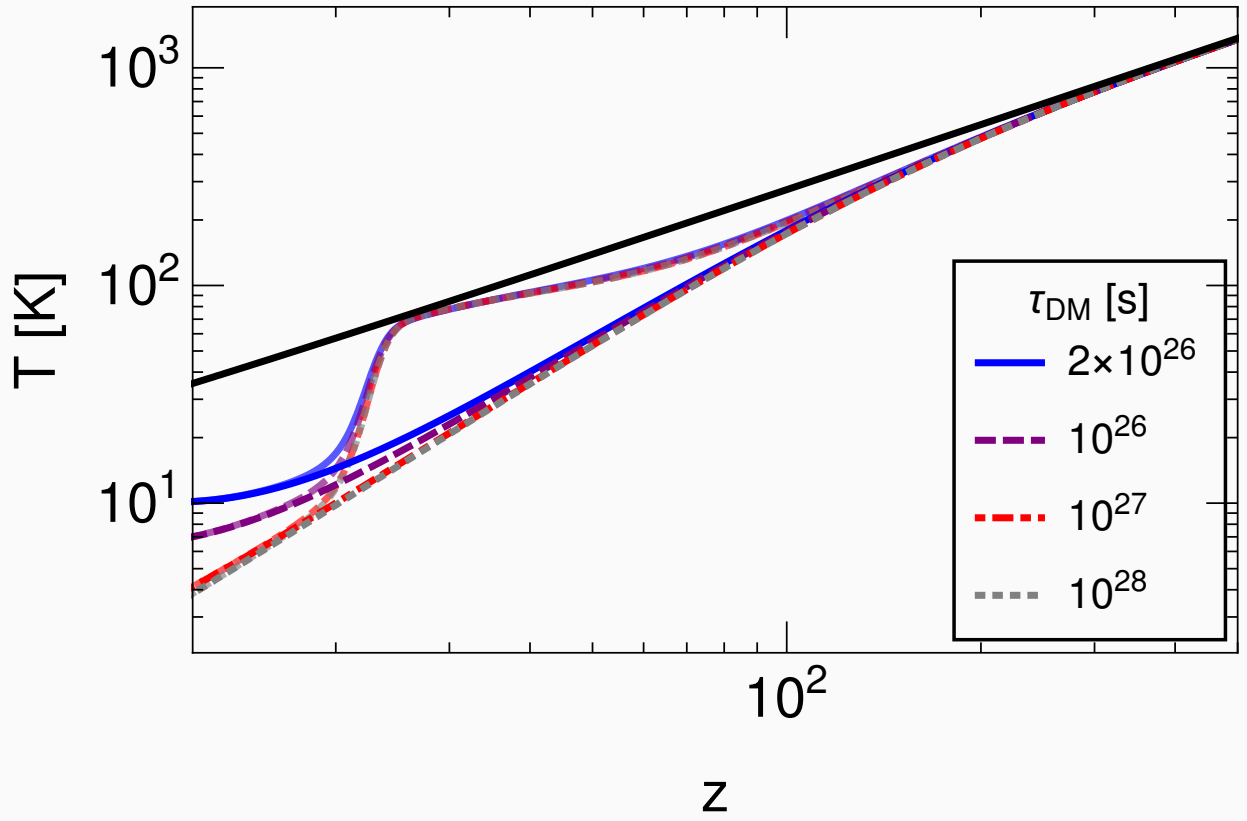
$$T_{21} \approx \tau \frac{T_{\rm S} - T_{\rm CMB}}{1+z} \qquad T_{\rm S} = \frac{T_{\rm CMB} + y_{\rm c} T_{\rm IGM} + y_{{\rm Ly}\alpha} T_{{\rm Ly}\alpha}}{1 + y_{\rm c} + y_{{\rm Ly}\alpha}}$$



*Zaldarriaga, Furlanetto, and Hernquist; arXiv:astro-ph/0311514

Wouthuysen-Field Effect*

$$T_{21} \approx \tau \frac{T_S - T_{CMB}}{1+z} \qquad T_S = \frac{T_{CMB} + y_c T_{IGM} + y_{Ly\alpha} T_{Ly\alpha}}{1 + y_c + y_{Ly\alpha}}$$



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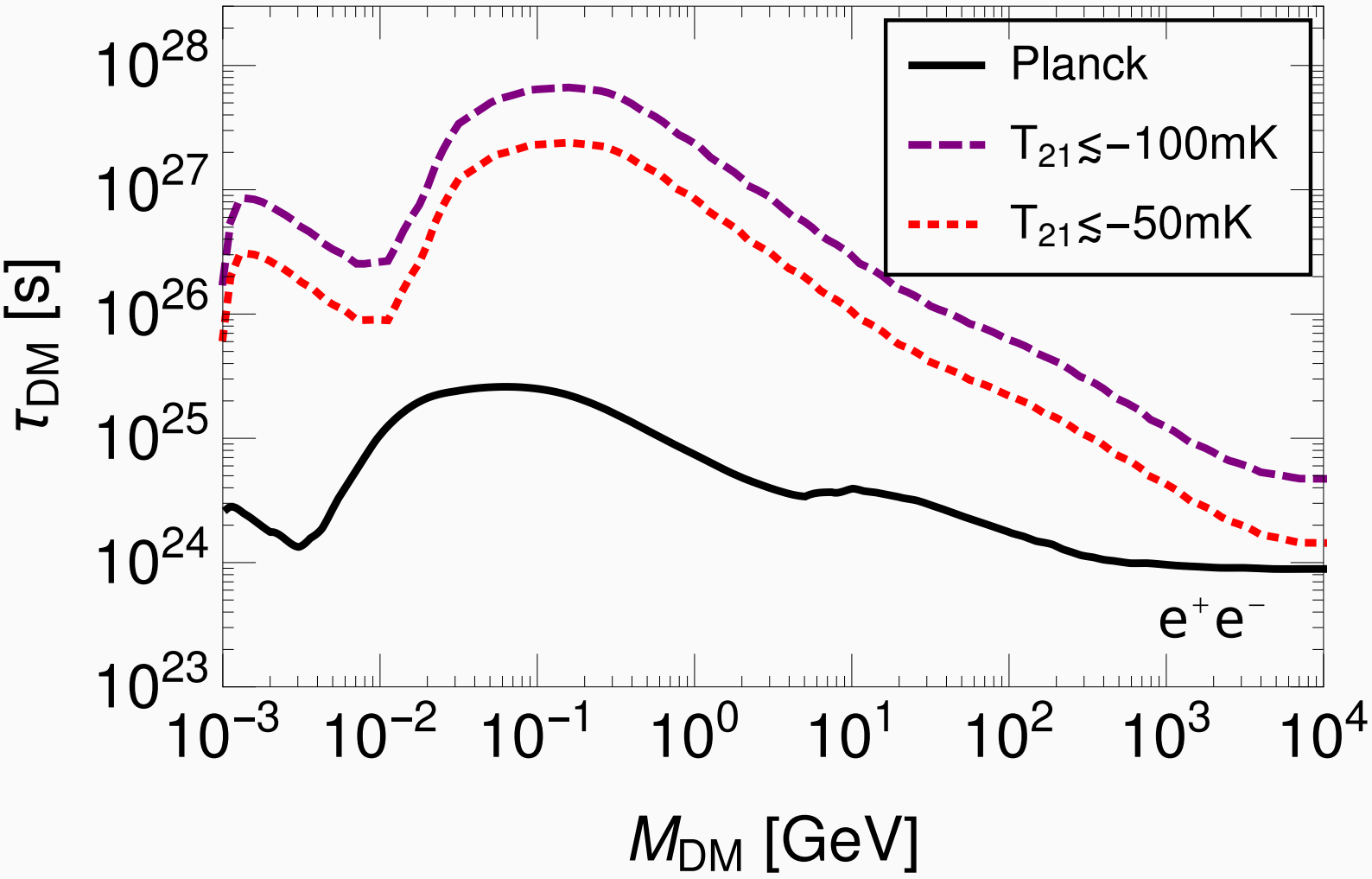
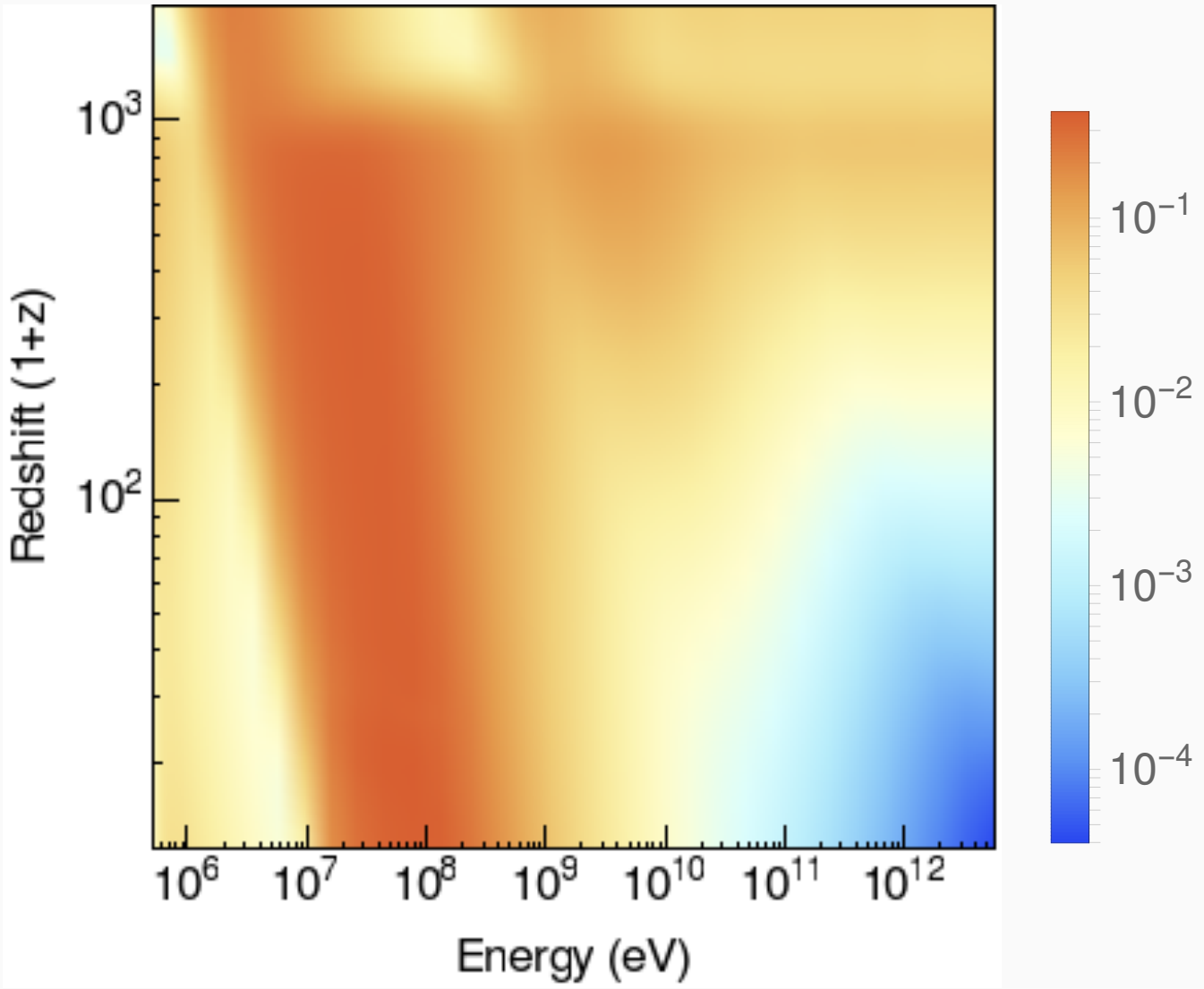
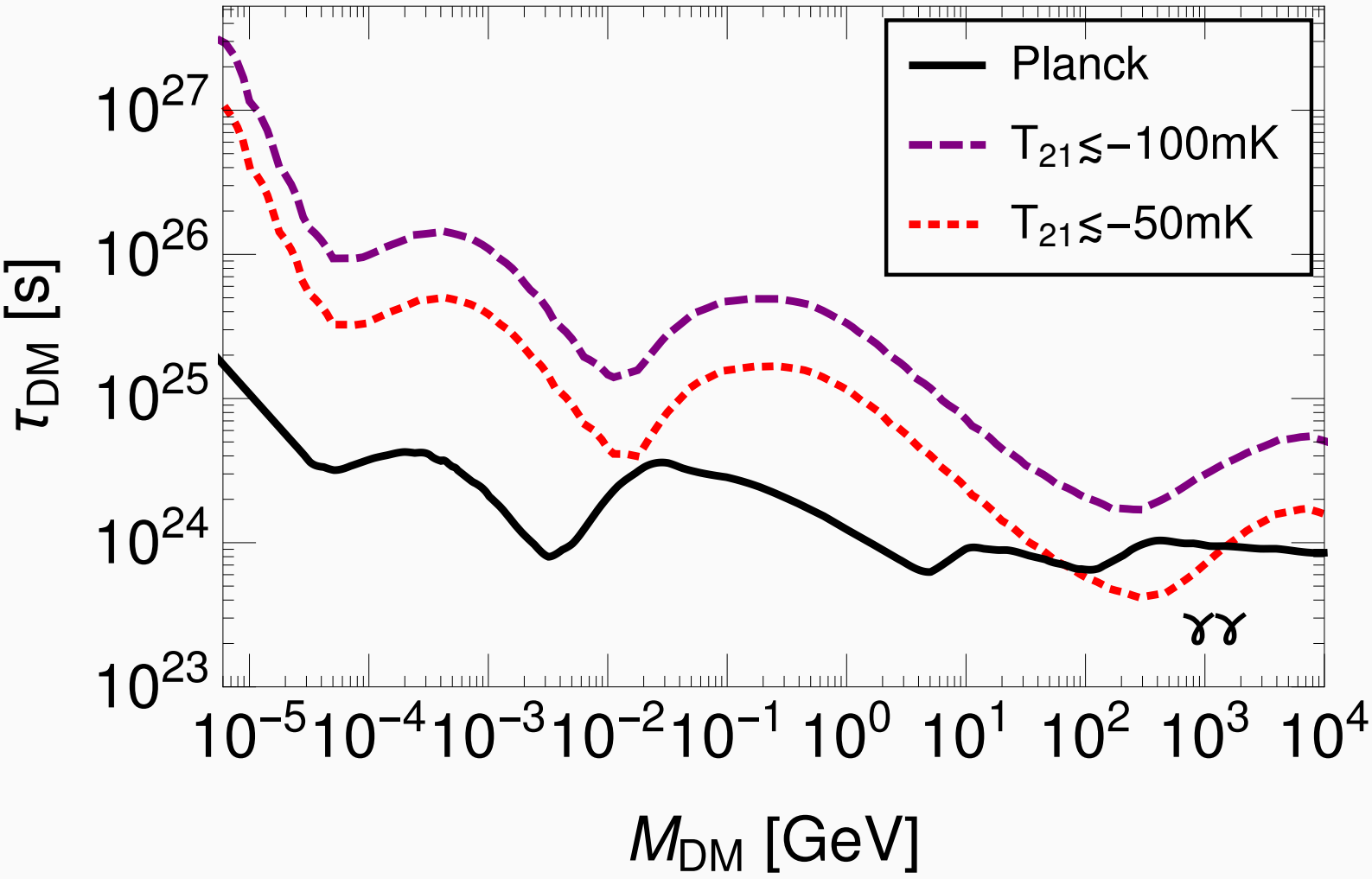
Decaying Dark Matter Constraints



Decaying Dark Matter Constraints



Decaying Dark Matter Constraints



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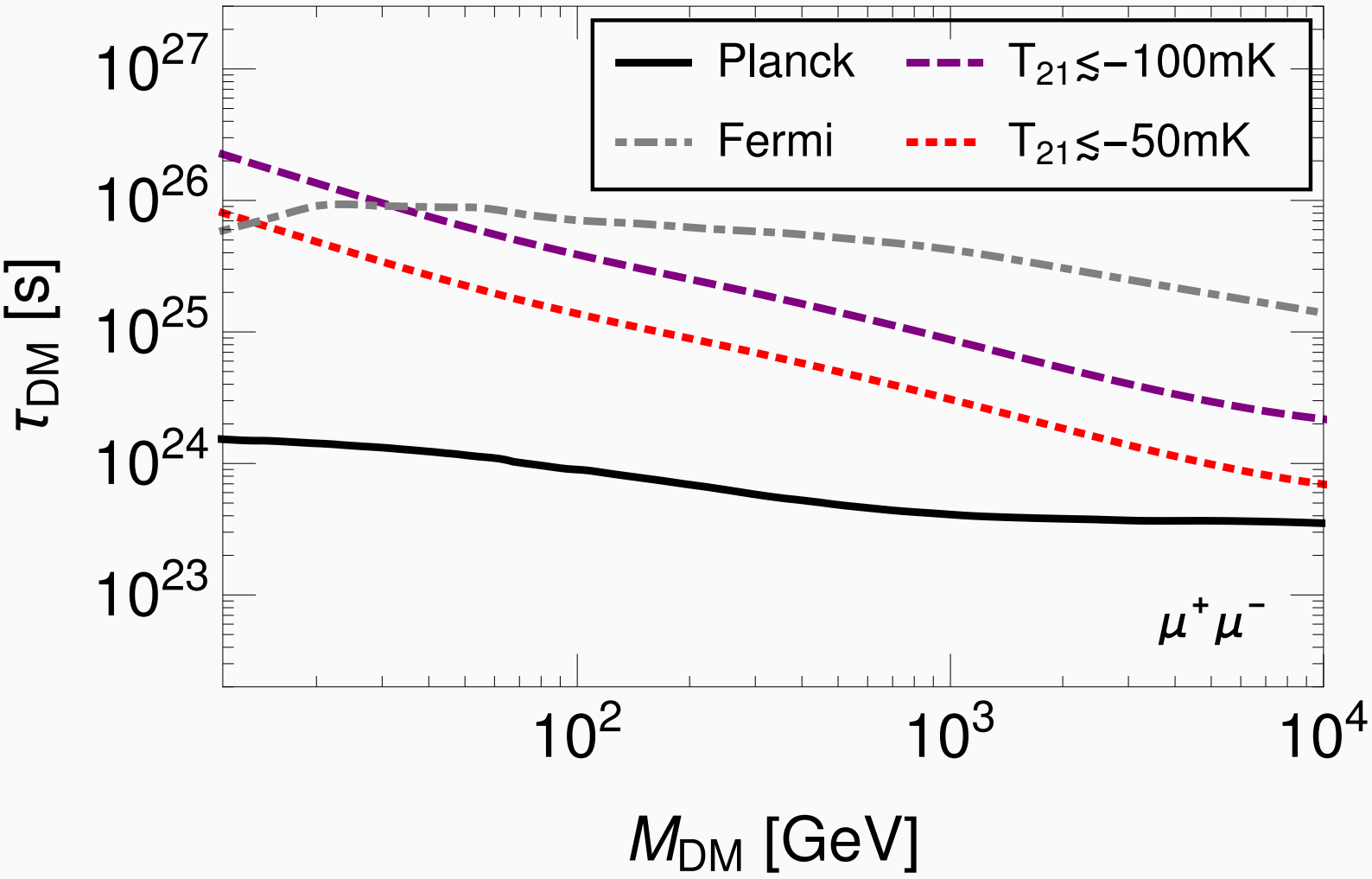

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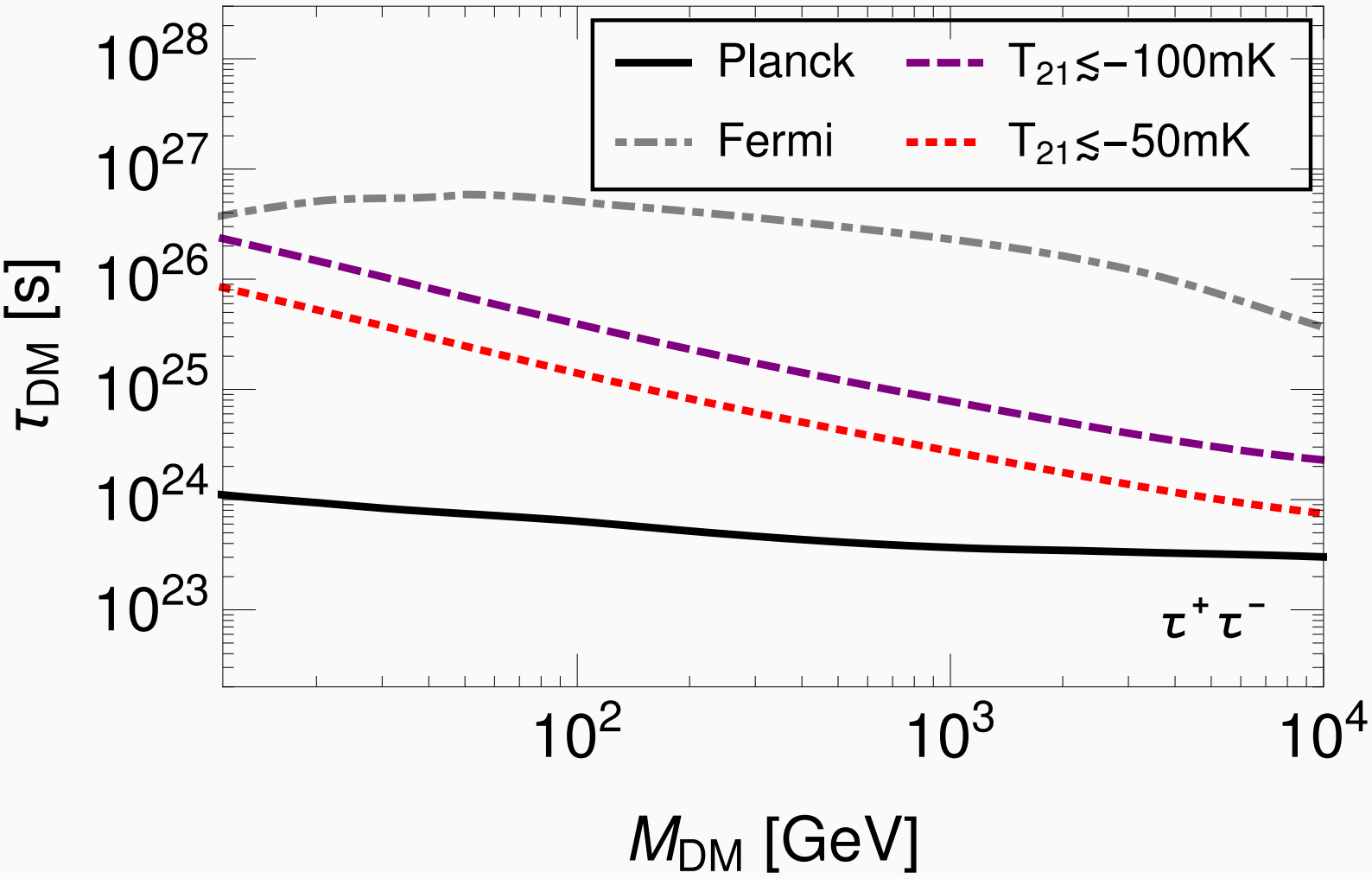
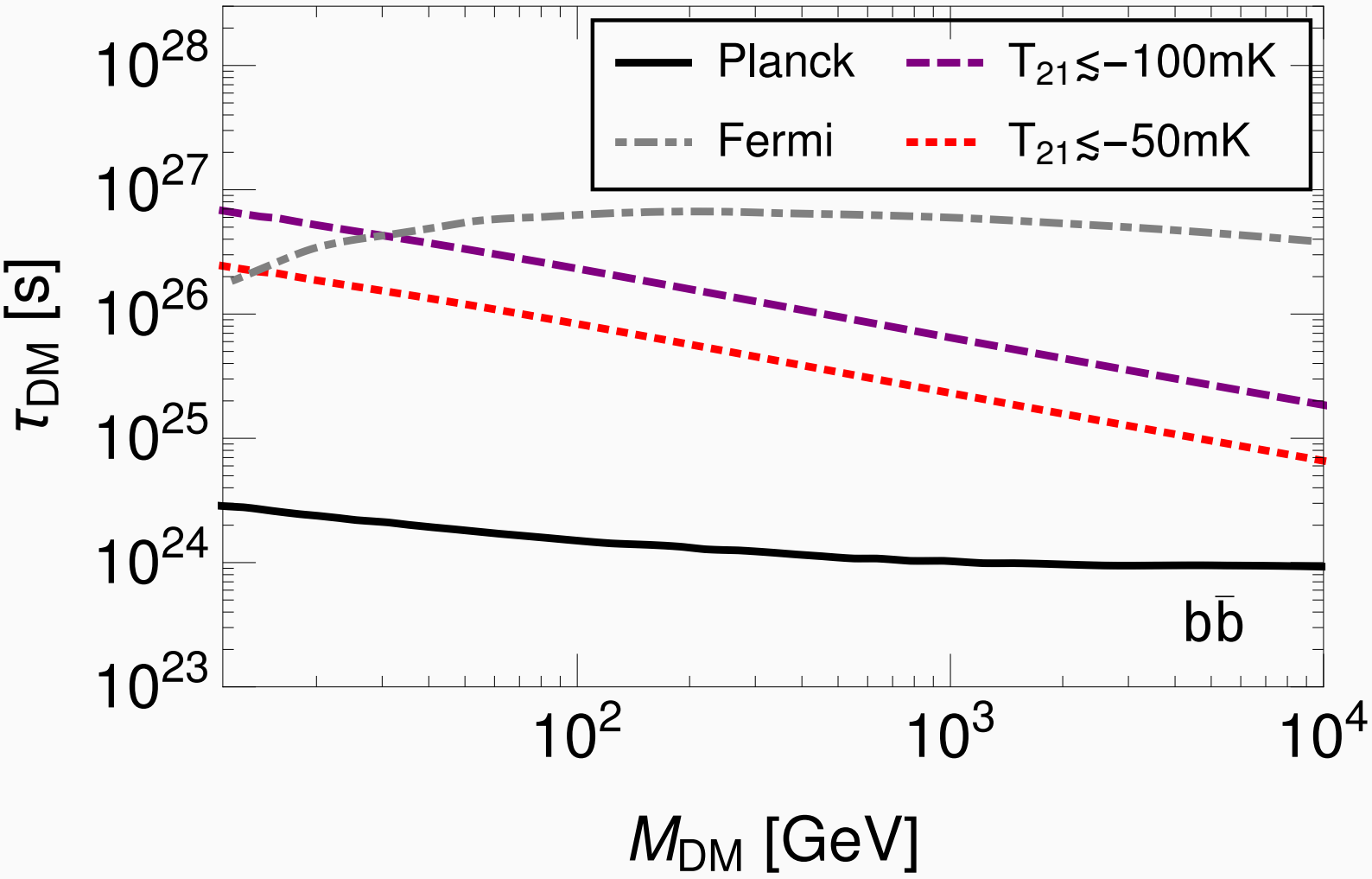
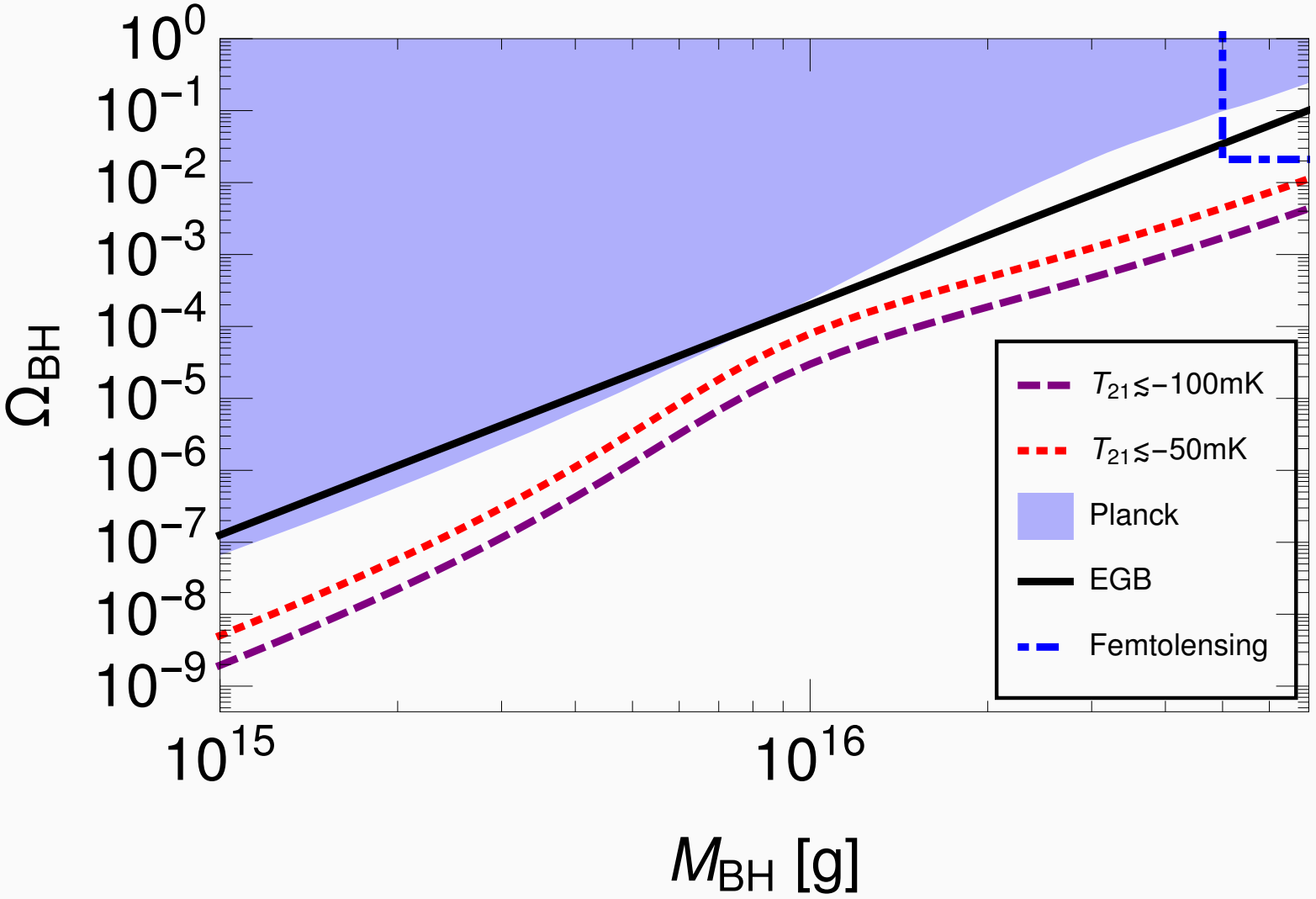


Decaying Dark Matter Constraints



PBH Constraints



Conclusions

21cm allow for measurements during the classically dark age of the Universe.

21cm measurements can place stringent constraints for decaying dark matter and PBH models.

Thank You